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SOME FEATURES OF THE ANNUAL TEMPERATURE REGIME IN THE TROPICAL STRATOSPHERE

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ABSTRACT

The annual temperature regime in the tropical stratosphere between 100 mb. and 10 mb. is examined on the basis of five years of data from six stations, ranging in latitude from 9° N. to 34° N. The principal result of interest is the finding of a pronounced semiannual component in the temperature variation above the 30-mb. level (24 km.), especially at stations near the equator. It is suggested that this may be caused by the direct absorption of solar ultraviolet radiation by ozone in a region where the heating cycle is predominantly semiannual.

1. INTRODUCTION

The recent discovery of a 26-month zonal wind oscillation in the tropical stratosphere (Reed [9], Ebdon [2], Reed et al. [10], and Ebdon and Veryard [3]) has emphasized the need for greater study of this little-explored region of the atmosphere. Veryard and Ebdon [12] have extended their wind investigations to include the longer-period temperature fluctuations and have offered convincing evidence that the 26-month wind oscillation is accompanied by a temperature fluctuation of corresponding period. The purpose of the present paper is to call attention to some interesting features of the annual temperature regime. In particular it is shown that a pronounced semiannual component is present in the annual temperature curve at heights above about 30 mb. (24 km.).

It is believed that, at least near the equator, the semiannual component is a consequence of the absorption of solar ultraviolet radiation by ozone in a region where the heating cycle is essentially semiannual. However, no attempt is made to develop a quantitative theory of the temperature variations or to infer their effects on the wind circulation. The object here is simply to present a preliminary description of the temperature regime, based on the meager data that are available.

2. DATA

The data used in this study consist of monthly mean temperatures at the stations and pressure levels listed in table 1. The data were obtained from the Climatic Center, U.S. Air Force by Mr. Sidney Teweles of the U.S. Weather Bureau.

It will be noted that at least five years of data were available for each station. Months excluded from the study are enclosed in parentheses. The number of observations appears to be sufficient to define the temperature regime adequately to the 30-mb. level at all stations. Above the 30-mb. level the number becomes quite small, and at 10 mb. it is not possible to determine reliable means for San Juan, Lihue, and Port Lyautey.

3. RESULTS

The main features of the temperature regime may be seen from figures 1, 2, and 3. At Balboa (fig. 1) the temperature undergoes a pronounced annual variation at 100 mb. The amplitude of the annual cycle weakens with elevation, and at 30 mb. a semiannual variation

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Table 1.—*Number of observations for various months and pressure levels. Period of record appears below station, with missing months given in parentheses*

BALBOA, CANAL ZONE (9° N., 80° W.)
April 1952–March 1957

mb. \ mo.	J	F	M	A	M	J	J	A	S	O	N	D
100	199	215	228	174	167	151	191	210	211	222	196	207
50	146	152	153	101	99	106	131	157	165	162	134	149
30	127	132	126	80	89	83	101	126	131	137	108	120
20	94	102	88	53	55	43	80	86	83	101	99	90
10	18	25	18	7	4	11	12	14	9	21	10	21

GUAM (14° N., 145° E.)
December 1950–February 1956 (February, March, November 1951)

mb. \ mo.	J	F	M	A	M	J	J	A	S	O	N	D
100	236	267	269	240	273	232	226	213	235	255	174	244
50	154	190	198	142	164	160	153	151	173	171	107	136
30	123	150	153	104	147	125	116	108	131	129	94	110
20	81	101	91	53	91	82	79	55	78	81	64	72
10	20	8	7	6	20	15	16	13	17	10	21	11

CLARK FIELD, PHILIPPINES (15° N., 121° E.)
August 1950–January 1956 (November 1950, February, July 1951, January, May 1952)

mb. \ mo.	J	F	M	A	M	J	J	A	S	O	N	D
100	214	162	209	231	179	234	193	243	231	260	207	286
50	146	95	122	150	110	149	141	148	126	147	139	183
30	122	78	101	116	95	120	109	118	99	129	117	153
20	86	43	65	67	60	83	67	84	63	92	91	110
10	24	6	21	11	9	19	12	11	10	24	24	48

SAN JUAN, PUERTO RICO (18° N., 66° W.)
June 1952–May 1957

mb. \ mo.	J	F	M	A	M	J	J	A	S	O	N	D
100	291	245	288	254	250	235	268	296	258	261	267	275
50	232	196	244	203	187	189	215	246	205	206	219	222
30	177	133	179	125	129	97	116	149	134	144	159	177
20	63	41	49	32	40	22	29	38	52	48	62	55
10	2	—	—	1	—	—	2	—	2	1	1	2

LIHUE, HAWAII (22° N., 159° W.)
January 1952–December 1956

mb. \ mo.	J	F	M	A	M	J	J	A	S	O	N	D
100	234	239	248	253	263	276	295	295	278	237	207	242
50	126	157	175	210	220	242	273	269	242	162	117	130
30	71	81	112	155	143	164	194	213	163	94	66	71
20	36	25	39	54	44	43	66	85	60	36	19	31
10	1	—	1	1	—	—	1	—	1	2	1	2

PORT LYAUTEY, MOROCCO (34° N., 7° W.)
January 1953–January 1957

mb. \ mo.	J	F	M	A	M	J	J	A	S	O	N	D
100	182	115	144	127	138	128	112	99	104	140	125	147
50	121	71	100	78	106	79	70	56	81	97	81	94
30	65	49	68	47	66	47	30	28	45	50	42	50
20	21	25	25	20	33	19	11	6	11	13	9	7

appears which strengthens upward to at least the 10-mb. level. Similar traces are found at Clark Field (fig. 2). The variation is essentially annual at 50 mb. and 100 mb., while it is distinctly semiannual at 10 mb. The temperature regime at intermediate levels appears to be the sum of weak annual and semiannual components.

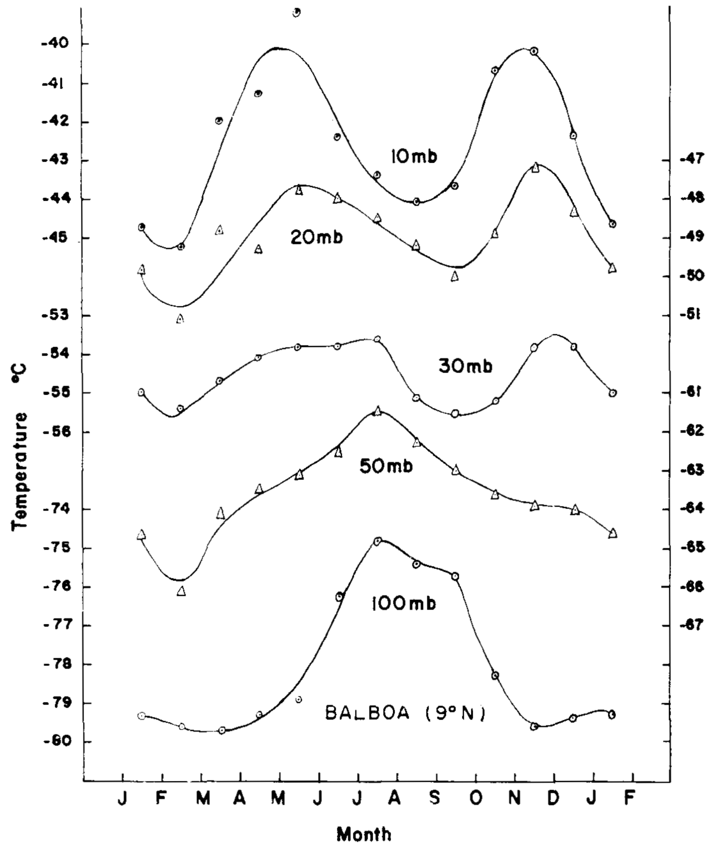

Figure 1.—Annual temperature regime at Balboa, Canal Zone (9° N.) at various pressure levels. Monthly mean temperatures are plotted at middle of month.

At Lihue (fig. 3), except for a minor irregularity at the 100-mb. level, only single maxima and minima are observed. However the temperature curve becomes increasingly skewed above the 50-mb. level, indicating the presence of higher harmonics. As a means, therefore, of separating annual and semiannual components and of achieving a more objective characterization of the temperature behavior, the records for the various stations were subjected to harmonic analysis. The results of this analysis, for the first and second harmonics, are presented in table 2. The columns headed "phase" give the time of maximum temperature for each component to the nearest week. The semiannual cycle has, of course, a second maximum 6 months later.

The main conclusions to be derived from inspection of the table are the following:

(1) The semiannual oscillation has its greatest amplitude (about 2° C.) at the stations nearest the equator and at the highest levels observed. The amplitude diminishes poleward and downward, reaching a minimum near 50 mb.

(2) The semiannual temperature maxima occur somewhat earlier at the higher levels, at least for the stations nearest the equator. Near 50 mb., where the amplitude is small, the phase is erratic. Below the 50-mb. level the phase is again earlier.

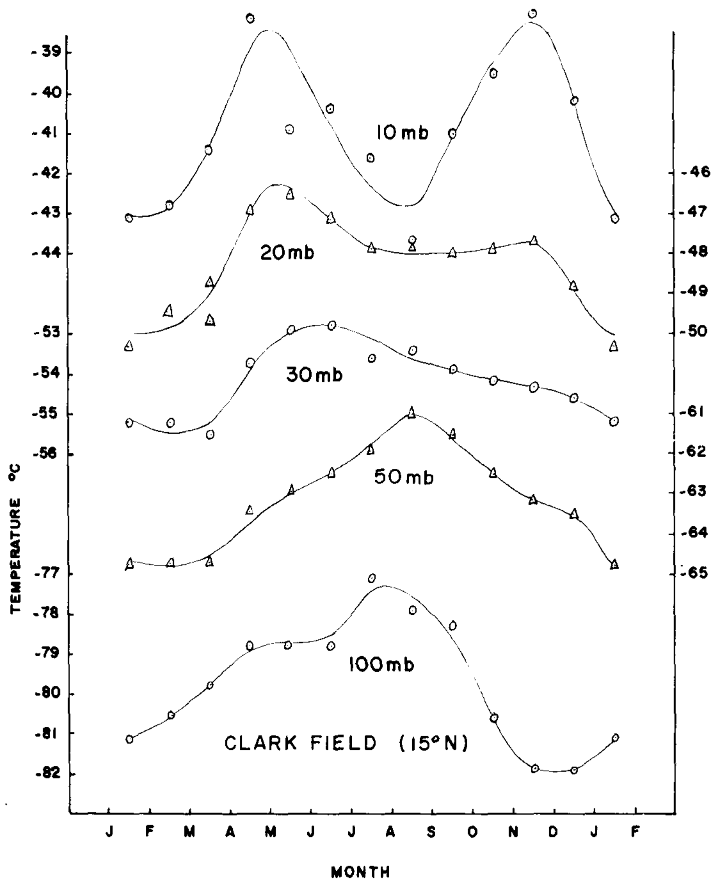

FIGURE 2.—Annual temperature regime at Clark Field, Philippines (15° N.) at various pressure levels. Monthly mean temperatures are plotted at middle of month.

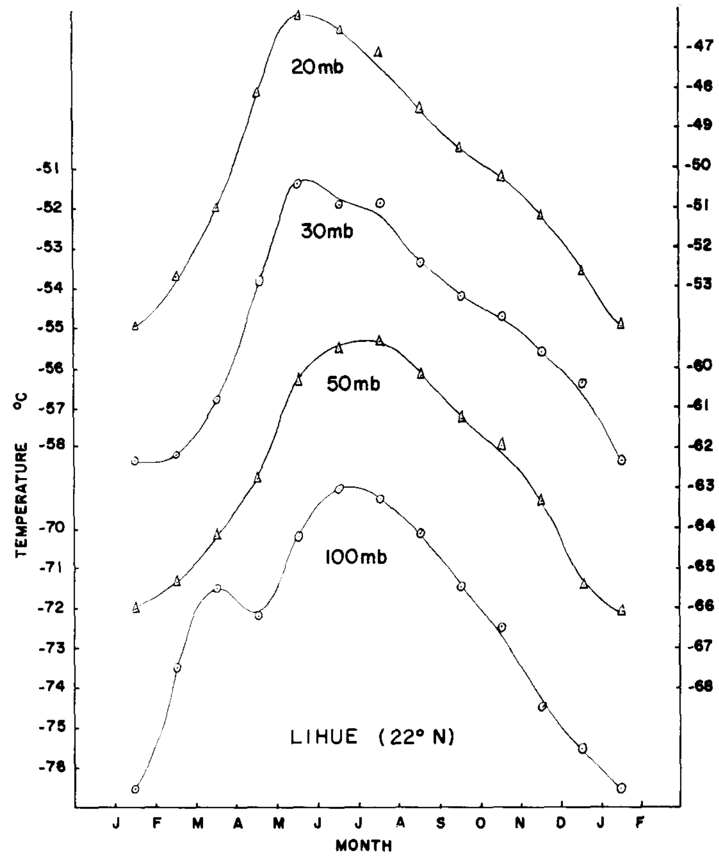

FIGURE 3.—Annual temperature regime at Lihue, Hawaii (22° N.) at various pressure levels. Monthly mean temperatures are plotted at middle of month.

(3) The amplitude of the annual cycle diminishes upward south of 20° N. At Lihue (22° N.) it is roughly constant with height, and at Port Lyautey (34° N.) a change to an upward *increase* of amplitude occurs. In general the amplitudes are greater to the north.

(4) There appears to be a slight tendency for the annual temperature maximum to occur earlier at the higher levels, at about the time of the solstice. At 10 mb., where the amplitudes tend to be small, the phase is erratic.

4. REMARKS

The presence of a semiannual temperature oscillation in the vicinity of the equator at levels above 50 mb. is not surprising when it is recognized (1) that the heating cycle at the equator is predominantly semiannual, and (2) that there exists in the stratosphere a substance—ozone—which directly absorbs the solar ultraviolet radiation. According to Craig [1] and Murgatroyd and Goody [8], the bulk of the ozone layer is nearly in radiative equilibrium, thus in the upper part of the layer, where most of the absorption of solar radiation occurs, the temperature changes should parallel the changes in incoming radiation. However it remains to be shown that the foregoing explanation is quantitatively correct.

Moreover there are grounds for believing that variations in radiative intensity cannot explain all features of the temperature curves. It will be recalled that the curves at 10 mb. for Balboa (9° N.) and Clark Field (15° N.) are nearly identical, yet from the graphs of daily insolation in figure 4 noticeable differences are to be expected. The pronounced semiannual variation at Clark Field and the skewed variation at Lihue (22° N.) are not in good agreement with the radiation curves. Perhaps the simplest explanation for the discrepancies is horizontal mixing processes which cause the equatorial temperature regime to appear in weakened form at distances well removed from the equator.

Also the delay in arrival of the semiannual temperature wave at the lower levels suggests the presence of heat transfer processes other than radiative exchange. Eddy conduction in the vertical constitutes one possible process of importance. According to Craig [1], the main heating occurs in the upper part of the ozone layer, near 40 km.

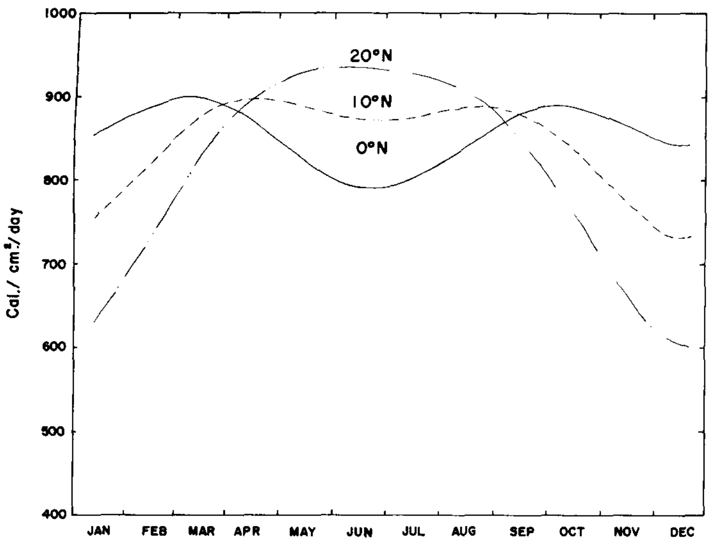

FIGURE 4.—Total daily solar radiation at top of atmosphere in cal./cm.^{2} at the equator and at 10° N. and 20° N. (After List [7]).

Thus large temperature changes at this level may be conducted downward through the atmosphere with gradually diminishing amplitude, much as the annual heating cycle at the earth's surface is conducted into the ground.

If it is assumed that the downward propagation of a temperature wave of period P is solely the result of eddy conduction, the phase lag t between levels z_2 and z_1 may be computed from the formula (Haltiner and Martin [5])

$$t=\frac{1}{2}\sqrt{\frac{P}{\pi K}}\,(z_2-z_1) \tag{1}$$

where K is the eddy diffusivity. For a period of 6 months and K of 10^4 cm.^{2} sec.$^{-1}$ (according to Lettau [6] a large value for the heights in question), the lag between 30 km. and 25 km. is approximately 2 months, as compared with an observed lag of less than 1 month (table 2). In view of the uncertainty in K, the disagreement is not sufficiently large to rule out eddy conduction as a factor in the temperature behavior. However it does encourage the search for still other factors of importance.

In this respect the possible importance of dynamical processes should not be overlooked. Greenhow and Neufeld [4] have recently shown from radar observation of ionized meteor trails that the zonal wind component in the 80–100-km. layer at Jodrell Bank, England, (53° N.) undergoes a pronounced semiannual variation. It is difficult to conceive of a purely radiative mechanism which could account for such a variation.

In concluding this section it should be noted that stratospheric temperature measurements are subject to considerable error because of the heating of the temperature element by solar radiation (Teweles and Finger [11]). However the fact that the temperature changes do not correspond too closely to the variations in incoming radiation makes it extremely unlikely that the main effects noted here are caused by instrumental error.

TABLE 2.—*Amplitudes and phases of annual and semiannual components of temperature variation at specified pressure levels and the ratio, r, of amplitudes (6-month/12-month). Phase gives time of maximum temperature to nearest week*

Station	6-month component		12-month component		r
	Amplitude (° C.)	Phase	Amplitude (° C.)	Phase	
10 mb.					
Balboa	2.3	May 7	0.4	June 15	5.7
Guam	1.8	May 7	1.4	Apr. 15	1.3
Clark Field	2.1	May 7	0.2	Oct. 1	10.5
20 mb.					
Balboa	1.2	May 22	0.4	Aug. 1	3.0
Guam	1.1	May 22	0.6	June 7	1.8
Clark Field	1.0	May 7	1.1	July 15	0.9
San Juan	0.9	May 7	1.0	July 1	0.9
Lihue	1.0	May 7	3.3	July 1	0.3
Port Lyautey	0.6	Mar. 15	3.6	June 15	0.2
30 mb.					
Balboa	0.9	June 1	0.4	May 22	2.2
Guam	0.7	May 22	1.8	June 15	0.4
Clark Field	0.5	May 22	1.0	July 15	0.5
San Juan	0.4	May 15	1.2	July 1	0.3
Lihue	1.2	May 15	3.0	July 7	0.4
Port Lyautey	0.4	Apr. 1	3.6	July 7	0.1
50 mb.					
Balboa	0.3	June 15	1.4	July 15	0.2
Guam	0.2	Feb. 15	2.0	Aug. 1	0.1
Clark Field	0.1	Apr. 1	1.7	June 15	0.1
San Juan	0.4	May 7	2.7	July 1	0.1
Lihue	0.4	May 15	3.3	July 1	0.1
Port Lyautey	0.6	Apr. 15	2.6	July 15	0.2
100 mb.					
Balboa	1.0	Feb. 1	2.0	Aug. 7	0.5
Guam	0.6	Mar. 1	3.5	Aug. 1	0.2
Clark Field	0.7	Feb. 22	2.0	July 1	0.3
San Juan	0.6	Feb. 15	2.7	Aug. 7	0.2
Lihue	0.6	Feb. 22	2.9	July 1	0.2
Port Lyautey	0.8	May 7	2.2	Mar. 1	0.4

5. CONCLUSIONS

At levels above 30 mb. (24 km.), a pronounced semiannual component appears in the annual temperature curve. This component increases in amplitude with elevation and is strongest nearest the equator, though it is still appreciable at 22° N.

The absorption of solar ultraviolet radiation by ozone in a region where the heating cycle is approximately semiannual could account qualitatively for the semiannual temperature variations near the equator. However there are several features of the temperature regime which suggest that other heat exchange processes may also be of importance.

Although it is not too early to begin formulating theoretical ideas regarding the phenomena discussed here, it is felt that additional observational studies are more urgently needed at this time in view of the limited data upon which these results are based.

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